ADSORPTION POTENTIAL OF MODIFIED CELLULOSE FROM INVASIVE WEEDS ON DYES REMOVAL

SYNOPSIS

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INTRODUCTION:

Environment pollution has become unavoidable in present time due to adoption of modern lifestyle, technologies and vast industrialization. The degradation of natural resources, population, modernization and over industrialization are main causes for degradation of environment quality. The unplanned exploitation of water resources has limited the availability of clean water. Water resources are prone to pollution by wastes from human households or chemicals discharged from factories and hence get easily contaminated. Heavy metals and organic compounds like dye effluents are main contaminants in wastewater discharged from various sources. Water pollution due to toxic metals and organic dyes effluents is a matter of global concern as these are known to be toxic and carcinogenic. The removal of these contaminants and treatment of wastewater from dye- manufacturing industries or textile industries is a major challenge as these contaminants are non- biodegradable in nature. The dyes are the major waste in industrial effluents and discharged during dyeing and rinsing process. Synthetic dye effluents in the aqueous solutions are considered to be the most toxic pollutant as colour is a primary and visible indicator of contamination in water. It has been estimated that 20% water pollution is due to dyes only (Kant, 2012). Dyes have been extensively used in industries such as textile, paper, plastic, printing, leather, photo-electrochemical cells, hair colouring products, food and cosmetic industries (Gusmao et al., 2013). Discharge of large amount of dyes in water deteriorates the physical and chemical properties of freshwater and seriously affects biodiversity, ecosystem functioning and natural activities of aquatic system including photosynthesis and Bio-chemical Oxygen Demand. The discharge of these toxic contaminants is unwanted and it poses serious effects to human as well as animals.

Presence of such coloured effluents in water is not only aesthetically unpleasant but may cause several other harmful impacts

- Dyes are lethal and can have acute and/or chronic effects on exposed fauna.
- Dyes may have carcinogenic, mutagenic properties and have a potential danger of bioaccumulation and bioaccumulation in food chain.
- Intense coloured dyes reduce sunlight transmission into water interferes with photosynthesis, biological activity and growth of bacteria.
- Complex molecular structures and aromatic nature makes them stable towards light and therefore cannot be treated with municipal waste treatment operations.

- Dyes are found highly toxic aquatic organisms as they consume dissolved oxygen resulting inbiochemical changes.

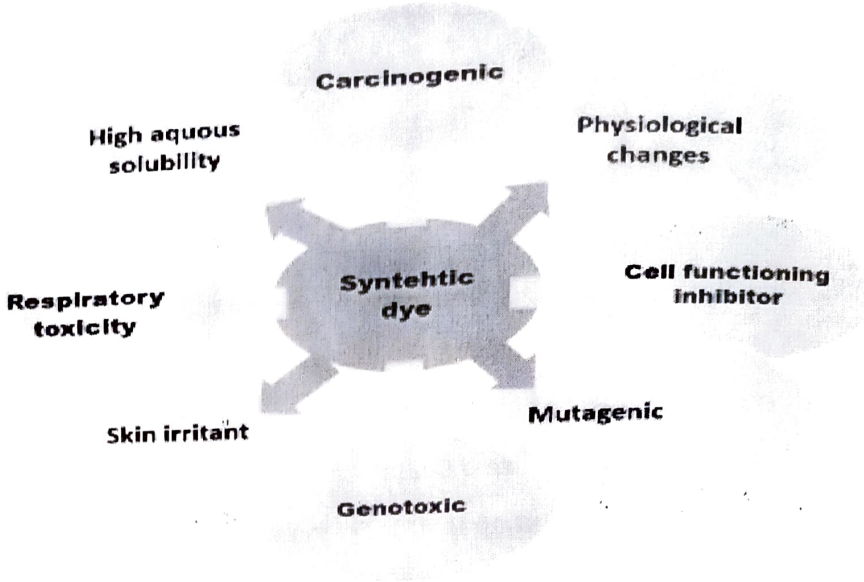

Figure 1: Harmful effects of Synthetic Dyes.

Synthetic dyestuffs can be classified in three broad classes: anionic, cationic and non-ionic dyes. Generally the cationic dyes are more toxic and harmful than the anionic dyes. Hence, a brief introduction to some of dyes is made here under.

Malachite Green: Malachite green [MG, $C_{23}H_{25}ClN_2$) commonly known as aniline green, basic green 4, diamond green B and Victoria green B is a basic cationic dye. The IUPAC name of MG is 4-{[4-(dimethyl amino) phenyl] (phenyl) methylidene}-N, N-dimethylcyclohexa-2, 5-dien-1-iminium chloride. The intense green solution of MG in water is due to a strong absorption band at 621 *n*m (extinction coefficient of 10^5 $M^{-1}cm^{-1}$). Malachite green is used as food colouring agent, food additives and in silk, wool, leather, cotton and paper industries (Culp & Beland, 1996). The use of this dye has become controversial because it has carcinogenic and genotoxic properties. The chemical structure of MG is presented below:

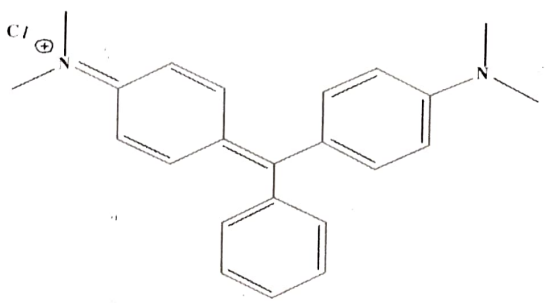

Figure 2: Chemical structure of malachite green.

Congo Red: Commonly called Direct Red-28 and Cotton Red is an anionic benzidine diazo direct dye. It contains $-NH_2$ and $-SO_3$ functional group existing as brownish-red crystalline solid. The IUPAC name of Congo red is sodium salt of 3, 3'- ([1, 1'-biphenyl]-4, 4'-diyl) bis (4-aminonaphthalene-1-sulfonic acid).

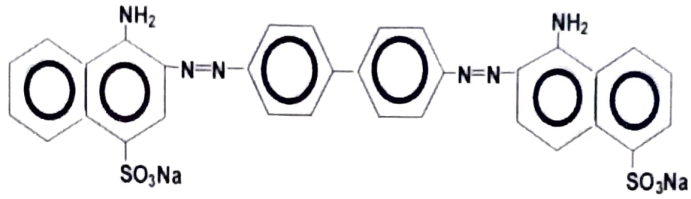

Figure 3: Molecular structure of Congo red dye.

The dye is commonly used in textile industries. Harmful effects include skin, eye gastrointestinal irritation and respiratory disorders.

Methylene Blue: Methylene blue ((MB, $C_{16}H_{18}N_3SCl$), It is a water soluble basic cationic dye. The IUPAC name of MB is 3,7-bis(dimethyl amino)-phenothiazin-5-ium chloride. MB is most commonly used in silk, paper, textile industries and hair colouring products. Hazardous effects include respiratory disorder, burning sensation, vomiting and gastritis.

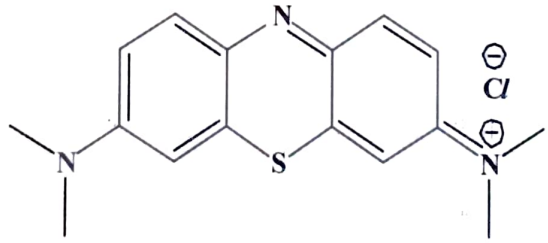

Figure 4: Chemical structure of methylene blue.

Methyl Orange: Methyl orange (MO, $C_{14}H_{14}N_3NaO_3S$) used as a weak acid–base indicator is an anionic dye. Its IUPAC name is Sodium 4[(4dimethylamino) phenyl diazenyl] benzene sulfonate. It is used in various industries and poses serious health hazards. The latter include breathing problem, vomiting, diarrhea and nausea. The chemical structure of MO is as presented as

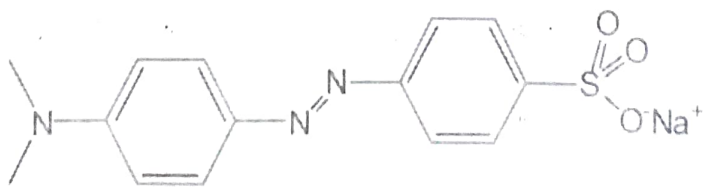

Figure 5: Chemical structure of methyl orange.

Hence, from the above discussion it can be concluded that the removal of toxic dyes from the industrial wastewaters before discharge into the aquatic ecosystem is very important for the worldwide concern of environmental protection.

Methods for Treatment of Textile Dye Wastewater: The complex chemical structure, water soluble, recalcitrant and non-biodegradable nature of toxic dyes poses a serious challenge and difficulty treatment techniques bioremediation of water (Liu & Pan, 2012). Various physical, chemical and biological methods has been investigated for waste water treatment. Some of reported methods are adsorption (Purkait, et al., 2007), nanofiltration (Capara, Yetisa & Yilmazb, 2007), ultrasonic decomposition (Jiantuan, 2004), coagulation and precipitation (Liu, Chiu & Yeh, 2003), advanced chemical oxidation (Arslan, Balcioglu & Tuhkanen, 2003), electrochemical oxidation (Riera-Torres &Gutiérrez, 2010), photo-oxidation and membrane-based separation processes (Purkait, Gupta & De, 2006] etc. Most of these advanced treatments are unsatisfactory, costly and produces of extra wastes. Out of all these methods, adsorption involves low initial investments and offer best results (Sharma et al. 2011). It is one of the easy, most efficient and inexpensive techniques for the treatment of wastewater. Development of efficient, cost friendly, disposable and green based adsorbents is attracting more research attention nowadays. Utilization of agricultural waste and non-useful plant biomass for development of adsorbent can solve economic as well as environmental issues. Invasive plant weeds are non-edible and affects native vegetation but are rich in lignocellulosic biomass. So, these can be wisely managed for various value-added applications.

Invasive alien plants species: Invasive Alien species is non indigenous species which are evolved elsewhere and have been deliberately or accidentally introduced in area where it does not occur naturally and has significant dispersal potential. There are so many obnoxious weeds that are invasive and has consumed a large expanse of lands and has imposed a great threat to other vegetation, land productivity, grazing livestock, biodiversity and consequently to the overall ecology (Pass, 1991). Some of invasive alien plant species reported very troublesome in India are *Parthenium hysterophorus L., Lantana camara L., Eupatorium odoratum L., Hyptis suaveolens (L) Poit.* and *Ageratum conyzoides L.* Their rapid growth over pass the native biota in terms of habitat occupation and exploitation of water and nutritional resources. Plant invasions is unavoidable process and have been recognized as emerging global threat (Mooney & Hobbs, 2000; Vitousek et al., 1997). These species displaces the native vegetation by competing and

suppressing their growth. Invasion of such species also changes the composition and dynamics of soil. Some of factors that support their invasiveness are:

- Ability to grow in wide range environment
- Resource uptake efficiency
- Rapid growth and high seed production.
- Short life cycle
- Modify invaded environment
- Overshadow native plants
- Resistant to grazing pests and diseases.

Figure 6: Invasiveness of Alien Plants.

Like environment pollution, rapid growth of invasive alien species is a serious matter of concern. These are posing significant threat to biodiversity, forest ecosystem, agricultural production, soil dynamics and human health (Cronk and Fuller, 1995). So, the control over growth of such plants is urgently needed. Use of weedicides is not thoughtful to control their growth because it adds more harmful chemicals in environment.

However, these invasive plants are rich in lignocellulosic biomass and can be utilized as biopolymer feedstock for value added products. This biomass can be effectively managed with low initial installments for extraction of biopolymers.

Lignocellulosic biomass is the most promising feedstock and provide a unique natural vast resource for cost effective bio-energy collection due to inexpensive,non-toxic renewable, biodegradable and abundant nature.

Composition of Plant Biomass: Lignocellulosic biomass has complex internal structure. Cell wall of lignocellulosic biomass consist of major biopolymers cellulose, hemicellulose and lignin. Cellulose is the most abundant, low-cost biopolymer. Hemicellulose and lignin being less abundant and underutilized material as compared to

cellulose. Cellulose constitutes 40-50% of biomass and consists ofa linear chain of D–anhydro glucopyranose units linked by β–(1→4) glycosidic bonds with a degree of polymerization (n) = 10,000 to 15,000 (Moon et al., 2011).

Fractionation of Lignocellulosic Biomass: Separation and isolation of different components of biomass is the first step in bio refineries. As cellulose is most abundant and easily separable biopolymer, the present work focus mainly lies on separation and utilization of cellulose component. Various physical, chemical and physicochemical methods have been reported for separation of components of lignocellulosic biomass (Kootstra & Beeftink, 2009).

Out of these alkaline method of pretreatment seems to be very convenient, cost-effective and offers high yield of cellulose. Chemical treatment with non-polluting chemicals like NaOH, KOH and $Ca(OH)_2$ (Wang et al.,2012) is technically feasible process which does not require expensive chemicals and specially designed equipments.

Functionalization of Cellulose: Cellulose itself is very useful polymer which can further be modified by different means to variety of products. Cellulose backbone consists of hydroxyl groups which can be functionalized to create novel opportunities and new applications. Chemical modifications to cellulose derivatives enhance the application potential of cellulose. Cellulose can be modified into cellulose nanocrystals by acid hydrolysis (Peng, 2011). Cellulose functionalization involves etherification (Volkert & Wagenknecht, 2008), Tempo Oxidation (Da Silva Perez, Montanari & Vignon, 2003.), periodate oxidation (Sirvio et al., 2011) acetylation (Sassi & Chanzy, 1995) and Cellulose Crosslinking (Nada & El-Wakeel, 2006).

Applications of Cellulose–Based Materials: Cellulose is most abundant, renewable and non-toxic polymer, and possesses structural framework that can be modified to various useful products. It can be modified to various derivatives by different pathways for. Cellulose–based materials find specialty applications in fields like wastewater treatment (Ma, Li & Bao, 2015), drug delivery (Tran & Mututuvari, 2015), protein carrier, antimicrobial (Luo et al., 2013) and food industry (Murray et al., 2011).

Cellulose based adsorbents are material of choice for waste water treatment as chemical modification of cellulose enhances its activity as adsorbent. (Kamel, Hassan & Sakhawy, 2006) Various reports suggested the use of cellulose based adsorbents for dye removal (Luo & Zhang 2009) as metal ion sensor or heavy metal removal (Xu et al., 2013).

From above discussion it can be concluded that invasiveness of some plant species is problematic. Research efforts should be oriented towards management of these plant

weeds. In view of this, invasive weeds have been selected as substrate for present research work. This research work can contribute beneficial results about management and utilization of these weeds.

LITERATURE REVIEW:

Water Pollution due to dyes is a matter of concern nowadays. Although, there are many physical, chemical and biological methods available but they are expensive, inefficient and offers unsatisfactory results. Adsorption is one of easy, inexpensive and convenient method which can be adopted for treatment of dye contaminated wastewater.In current time, research forces are oriented towards utilization of biodegradable, renewable and unexplored biomass for development of speciality products. This biomass is rich in valuable biopolymers which can be further modified to synthesise value added products. Synthesis of bio based adsorbents from such unexplored biomass is one of such approaches.

Invasive Alien Plant Species: Along pollution and diseases, invasiveness of certain alien plant species is emerging as major threat to ecology, biodiversity and environment. Some of these are plant species are *Parthenium hysterophorus* L., *Lantana camara* L., *Eupatorium odoratum* L., *Hyptis suaveolens* (L) Poit. and *Ageratum conyzoides* L. They have detrimental effect on floral and faunal ecosystem. In the present research work *Parthenium hysterophorus* L., *Lantana camara* L. and *Ageratum conyzoides* L. has been selected as material of choice for development of bio-based adsorbent.

A number of research studies and reports revealed that rapid growth of these species is a matter of global concern. Amit Kumar & Santosh Prasad have reviewed the threats of invasive alien plant species on integrity of biodiversity and ecology.

Ageratum conyzoides is also well known as billy goat weed spread over larger area of world (Holm et al., 1977).

Lantana camara L. is an invasive terrestrial weed introduced to India in 1809 as an ornamental plant for the Calcutta Botanical Garden. *L. camara* L. and *P. hysterophorus* L., have imposed a great threat to agricultural productivity, native vegetation, human health and overall ecology (Sharma, Makkar, & Dawra, 1988).

Virtuosic (1990) has suggested that biological invasions are major cause of environmental changes. Glowka et al., 1994 therefore recognized biological invasion as the second leading source of biodiversity destruction.

Inada et al., (1997) has suggested the management of weed by utilizing the lantana biomass for development of useful products and other biologically active agents.

Ricciardi, Neves & Rasmussen (1998) said that depletion of natural biodiversity is due to invasion of these species. Wilcove et al., (1998) stated that invasion of these species can significantly disrupt the native ecosystem and species diversity.Indigenous plant communities are reported to be disturbed by invasive alien plants globally (D'Antonio, Levine, & Thomson, 2001).

Kadirvelu et al., (2003) said that discharge of dye effluents from various industries is major cause of water pollution as these dyes are toxic and carcinogenic. Adsorption is identified as easy, inexpensive process for removal of dye from waste-water which is reliable and worldwide accepted (Bilal, 2004).

Ozacar & Sengil (2005) suggested adsorption of metal complex dyes from aqueous solutions by lignocellulosic biomass. Lignocellulosic biomass is rich in cellulose biopolymer which can be further modified to suitable adsorbents for treatment of dye contaminated water. Utilization of lignocellulosic biomass of invasive alien plant species for extraction of cellulose, development of adsorbent and other specialty products is best way for effective management of these weeds.

Varshney et al., (2006) reported the economic potentials of *Lantana camara* weed. Utilization of this weed can be effective method of its management. They suggested that biomass of *Lantana camara* contain appreciable amount of cellulosic fibres. They successfully isolated cellulose from *Lantana camara* by TAPPI T2003 OM-88 method with 94.80% yield. They further functionalized isolated cellulose by typical carboxymethylation reaction to water soluble carboxymethyl cellulose for variety of applications.

Naithani et al., (2008) proximately analysed *Parthenium hysterophorus* that it contained 78.0% holocellulose and 17.2% lignin. He evaluated *Parthenium hysterophorus* for pulp and paper making. He further suggested exploitable potential of these weeds, its conversion into derivatives for various industrial applications. According to Gaertner et al., (2009) their invasiveness and tendency to spread is out of control.

Later, Varshney & Naithani (2011) again reported isolation of cellulose from non-conventional sources and their further functionalization. They identified the proximate composition of cellulose in *Lantana camara* and *Parthenium hysterophorus* were 64.91% and 65% respectively by TAPPI T-203 OM 88 method. They further isolation a-Cellulose from *Lantana camara* and *Parthenium hysterophorus* with 38.76% and 37.4%

yield respectively. The yields after water Prehydrolysis were 95.5% and 92.2%, for *Lantana camara* and *Parthenium hysterophorus* respectively. Alkali Hydrolysis yields 85.9% from *Lantana camara* and 87.4% from *Parthenium hysterophorus.*

Functionalization of isolated cellulose was carried out by etherification reaction. The etherification reaction involved various routes like carboxymethylation, Cyanoethylation and Hydroxypropylation. The derivatized cellulose was employed for speciality applications.

Varshney & Sanjay Naithani (2011) concluded in their work that these plants have the potential to produce a-cellulose which can be further functionalized and the industries can utilize these biomass as an alternative feedstock to produce cellulose and saving wood. Their work suggested attractive way for management of these noxious weeds through their utilization for synthesis of commercially important products.

Begum & Mahbub (2013) reported the effectiveness of Carboxymethyl Cellulose extracted from lignicellulosic biomass for the Removal of Methylene Blue dye from aquous solution.

Cellulose is primary component and comprises 35-50% of lignocellulosic biomass. (Limayem & Ricke, 2012; Ghosh & Haldar, 2012) He further added that being lignocellulosic biomass, *Parthenium hysterophorus* contained Cellulose 27.8% and converted it successfully into lignocellulosic ethanol.

Amuda et al. (2014) reported adsorption potential of *Lantana camara.* He investigated the adsorption of Methylene Blue dye present in wastewater onto the activated carbon produced from *Lantana camara* stem.

Ezechi et al., (2015) has reported a study on *Ageratum conyzoide* weed. Their work involved the removal of methylene blue dyefrom synthetic effluents using *Ageratum conyzoide* leaf powder as adsorbent. The results suggested appreciable capability of *Ageratum conyzoide* leaf powder as adsorbents for removal of dye.

Banerjee et al., 2016 showed that lignocellulosic enriched *Lantana camara* biomass is a low-cost, readily available adsorbent for Methylene Blue and Rhodamine B. They further illustrated that acidic modification sorbent material increased the uptake capacity for dyes. Their work confirmed that modified *Lantana camara* is a considerable candidate for efficient removal of dye effluents.

Bapat & Jaspal et al., (2016) described the use of weed *Parthenium hysterophorus*, as powdered weed, activated carbon, ash etc. for water purification. They tested its

adsoption potential for several heavy metals and dyes. Their reviewed the adsorption tendency of this weed up to 90%.

Saini (2017) utilized the *Parthenium* biomass to physicochemical pretreatment for extraction of valuable material. He reported the production of cost-effective cellulase using *Parthenium hysterophorus* biomass as an unconventional lignocellulosic substrate. His work concluded the potential of weed biomass for cellulase production.

Laksono, et al., (2017) described the adsorption mechanism of Direct Red Dye on Cellulose based adsorbent from lignocellulosic biomass. They successfully isolated the cellulose with 21% yield from biomass and further undergo its derivatization. This work results suggested that cellulose based adsorbents can be utilized for dye removal from aquous solution.

Later, Suteua et al., (2017) also reported cellulose based adsorbent for removal of dye contaminated water.

Bharti et al., (2018) reported utilization of *Parthenium hysterophorous* biomass as low-cost substrate for cellulase and xylanase production. He concluded that it can be employed as suitable substrate for production of biopolymers.

*Ageratum conyzoides*is one of most harmful exotic weed thathas serious detrimental effects of crop productivity and ecosystem integrity. Saha et al.,(2018) stated that the weed is very common in cultivated area and affects the production of essential crops like rice, wheat, and maize.

However its biomass is cost effective source of lignocellulose. Saha, Khwairakpam & Kalamdhad (2020) performed several pretreatment experiments to identify the amount of lignin and cellulose in *Ageratum conyzoides*. His research results concluded that the weed biomass contained significant amount of cellulose.

Dutta & Bhat (2020) studied the adsorption of methylene blue dye onto NaOH modified lantana. They undergo adsorption process using unmodified and modified adsorbent synthesized from Lantana leaves powder. Their work showed that NaOH modified adsorbent was much effective as compared to the unmodified adsorbent.The research results concluded that *Lantana* leaves powder can be used as inexpensive adsorbent for the removal of dye from wastewater.

Pandey et al., (2021) reported the successful production of lignocellosic biofuel from *Ageratum conyzoides*. According to his research work the cellulose and hemicellulose content of *Ageratum conyzoides* was converted into sugars by acid hydrolysis. The sugars were further subjected to fermentation for synthesis of bio-ethanols.

Hizkeal et al., (2021) reported removal of dye from wastewater with cellulose based adsorbent. They investigated removal of Methylene Blue Dye by synthesising periodiated modified nanocellulose.

From above literature studies, it can be concluded that utilization of lignocellulosic biomass for isolation of cellulose and development of cellulose based adsorbent for water purification can be explored as biotechnological innovations.

RESEARCH GAP IDENTIFICTION:

Water pollution is a matter of global concern in today's time. Untreated synthetic dye effluents released from textile industries are main contributor of dye waste into the environment into the water system. There is urgent need of development of reliable, non-toxic and cost effective adsorbents for removal of dyes from wastewater. Lignocellulosic biomass is abundant, renewable and rich in cellulose that can be used for synthesis of bio-based adsorbents. Invasive alien plant species have been recognized as global threat because these are inedible and rapidly invade large land area. These weeds have devastating impact on agriculture, livestock production, biodiversity and carrying capacity of ecosystem (Sharma, Makkar & Dawra, 1988).

The problem of such weeds invasion can be effectively managed by utilizing their biomass as lignocellulosic substrate for development of cellulose based adsorbent. Few research work has been reported on utilization of these weeds and it is evident from literature studies that they have considerable content of cellulose (Ghosh et al., 2012) and potential as adsorbent for dye removal (Bapat & Jaspal, 2016). The studies on development of cellulose based adsorbent from these weeds have not been done yet. The present study will help in effective management and utilization of these weeds along with water purification.

OBJECTIVES:

- To isolate cellulose from collected weeds *Parthenium hysterophorus* L., *Lantana camara* L. and *Ageratum conyzoides* L.
- To functionalize extracted cellulose by various reactions.
- To study efficacy of modified cellulose as adsorbent for removal of Methylene blue, Congo Red, Malachite green and direct red.
- To characterize extracted cellulose and its modifications by FTIR, XRD and SEM techniques.

PROPOSED METHODOLOGY:

Material: In order to utilize the unexplored biomass, three invasive plant species *Parthenium hysterophorus* L., *Lantana camara* L. and *Ageratum conyzoides* L. has been selected as material of choice as lignocellulosic substrate.

Synthesis of Adsorbent:

Extraction of cellulose: *Parthenium hysterophorus* L., *Lantana camara* L. and *Ageratum conyzoides* L. is collected from local area. Plant material is washed, dried in oven and grind to fine powder. Extraction of cellulose is carried out from oven dried powder of plant biomass by alkali treatment to remove lignin and hemicellulose, then insoluble cellulose is filtered and bleached with $NaClO_2$(Da Silva Filho et al., 2009).Cellulose is filtered and dried at room temperature.

Preparation of nano cellulose from extracted cellulose: The extracted cellulose upon acidic hydrolysis H_2SO_4, with continuous stirring at 45 °C for 45 min yield nano cellulose (Dash, Li & Ragauskas, 2012). Addition of excess of distilled water is required to stop the hydrolysis reaction. The sediments containing nanocellulose is collected, washed with distilled water, sonicated for 30 min and centrifuged. The cloudy suspension containing nanocellulose is collected, then freeze dried for further use.

Periodate oxidation of Nanocellulose: Periodate oxidation of the cellulose nanomaterial is carried out by using $NaIO_4$ in a beaker covered with aluminum foil by and agitated at 50°C in the darkroom for about 4 hours. (Xu, Long & Li, 2019) Oxidation reaction is stopped by the addition of 1 g ethylene glycol, the reaction results in synthesis of nanocellulose dialdehyde.

Acetylation of Cellulose: Cellulose if further modified by acetylation reaction.Finally, the cellulose is acetylated using glacial acetic acid, sulfuric acid and acetic anhydride. (Cerqueira, Filho & Carla da Silva 2007)

Characterization: The extracted cellulose, nanocellulose and its modifications are characterized by Fourier transform infrared (FTIR) spectroscopy, scanning electron microscopy (SEM) and X-ray diffraction (XRD) to obtain the evidence of modification.

Adsorption Procedure: Adsorption studies are carried out with synthesized cellulose based adsorbent for Methylene Blue, Congo Red, Malachite green and Methyl Orange dyes by using a Photo lab 6600 UV–Vis spectrophotometer. Various adsorption parameters, such as the time, temperature, pH, and initial concentration of ion solutions are studied for evaluating performance of adsorbent.

Adsorption Kinetics: The efficiency of the absorbent was evaluated from the pseudo-first-order, pseudo-second-order. The rate constant of adsorption from the pseudo-first-order equation is determined from the following equation (Ho, 2004).

$$ln\,(q_e - q_t) = lnq_e - k_1 t$$

Where q_e and q_t are the adsorption capacities (mg/g) at equilibrium and time t, respectively, and k_1 is the rate constant for pseudo-first-order adsorption. From the plots of $ln\,(q_e - q_t)$ versus t, the values of k_1 and q_e were determined. The linear form of the pseudo-second-order kinetic model is expressed as (Ho, 2006).

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \left(\frac{1}{q_e}\right)t$$

where k_2 is the rate constant for second-order adsorption (g mg^{-1} min^{-1}) and is determined from the linear plot of t/q_t versus t.

Adsorption Isotherm: The Langmuir and Freundlich adsorption isotherms are used to describe the adsorption equilibrium over the entire concentration range studied. The saturated monolayer Langmuir isotherm can be represented as (Langmuir, 1916).

$$\frac{1}{q_e} = \frac{1}{bq_m}\frac{1}{c_e} + \frac{1}{q_m}$$

where C_e (mg/L) is the equilibrium metal ion concentration, q_e (mg/ g) is the amount of Congo red adsorbed on the adsorbent at equilibrium, and the parameters q_m(mg/g) and b (L/mg) are the Langmuir constants that relate $q_e$for a complete monolayer and energy of adsorption, respectively.

The Freundlich isotherm is expressed by the following equation.

$$\ln q_e = \ln K_F + \left(\frac{1}{n}\right) lnC_e$$

WhereK_F (mg/g) and 1/n indicate adsorption capacity and adsorption intensity, respectively. The plot of ln q_e versus ln C_e gives a straight line with a slope of 1/n and an intercept of ln K_F.

DISSERTATION/ THESIS OUTLINE:

Thesis will comprise five chapters as:

Chapter I (Introduction) includes the discussion of problem of water pollution due to dyes, impacts of uncontrolled invasions of alien weeds, importance and utility scopes of cellulosic content of lignocellulosic biomass and its bioconversions for various

applications. Need of management of invasive plants and objectives of study are included.

Chapter II (Literature Review) gives detailed review of published literature with reference water pollution due to dye, devastating impacts of invasive plants, and utility potentials of these plants for variable applications especially for dye removal.

Chapter III (Material and Methods) includes the required materials and methodology adopted for carrying out present investigation. Material, Methods and reaction procedures used are described in detail. Adsorption studies are also discussed.

Chapter IV (Results and Discussion) includes the detailed results obtained from present studies. Results regarding Yield of extracted and synthesised material is presented along with characterizations. Results of adsorption studies for dye removal are presented in tabular as well as graphical form.

Chapter V (Conclusion and Recommendations) includes brief and concise summary of the results. It suggested need of such unexplored studies. It also illustrates scope of further research on the basis of obtained results and successes.

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CERTIFICATE
(SYNOPSIS APPROVAL CERTIFICATE)

This is to certify that the Synopsis titled, **"Adsorption Potential of Modified Cellulose from Invasive Weeds on Dyes Removal",** submitted by **Ms. Divya Gautam** to the Career Point University, Hamirpur (H.P.), India in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in the **Department of Chemistry, School of Basic and Applied Sciences** has been approved by the Research Advisory Committee (RAC) after an Oral Examination of the student on dated 07/02/22.

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